COMPARISON OF PERFORMANCE IMPROVEMENT ON IMPELLER ROUND TIP AND FLAT TIP FOR PUMP AS TURBINE

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Abstract- A reverse running centrifugal pump is one of the attractive choices in micro-hydropower development and industrial pressure energy recovery. Pumps as turbines have been successfully applied in a wide range of small hydro sites in the world. Since the overall efficiency of these machines is lower than the conventional turbines, their application in larger hydro sites is not economical. Therefore, the efficiency improvement of reverse pumps is essential. In this study, by focusing on a pump impeller, the shape of blades was redesigned to reach a higher efficiency in turbine mode by modification in impeller tip. Modification was done by rounding the blade on impeller tip. After each modification, a new impeller was manufactured and tested in the test rig. The objective of this paper is to improve the efficiency of PAT by modification on impeller tip. In this paper, 3-D numerical CFD tool for simulation of the flow field characteristics inside the pump as turbine are analyzed and simulated by using Flow Simulation in ANSYS Workbench 17.0. According to the experimental and numerical result, the efficiency of impeller round tip is greater than flat tip.

Keywords- Modification, Impeller Tip, Efficiency, Blade Rounding.

I. INTRODUCTION

The development of any country depends upon availability of electrical energy and its per capita energy consumption, which is regarded as an index of national standard of living in the present civilization. Energy is considered as the basic input for any country for keeping the wheels of its economy moving. In rural, remote and hilly areas , power scenario is characterized by poor and unreliable supply of energy. World has started running out of oil and it is estimated that 80% of the world's supply will be consumed in our lifetime. Moreover, the pollution hazard arising out of fossil fuel-burning has become quite significant in recent years. Thus, it has become utmost important to look for renewable energy sources such as hydro, solar, wind and energy from ocean tides. Among all the available renewable energy sources, hydropower is considered as the most promising source of energy.

Reverse-running centrifugal pumps (also called pumps as turbines or PAT) are a solution for generating and recovering power in small and micro hydropower situations. Pumps are relatively simple machines, inexpensive (compared to a hydraulic turbines), and readily available worldwide. It has been estimated that the capital payback period of a reverse running pump in the range of 5–50 kW is less than two years [1,2]. Moreover, the use of PAT could be suitable because manufacturers of turbines worldwide are less numerous than pump producers, the market for turbines is smaller compared to pumps, and pumps are mechanically simple and require less maintenance.

Singh [3] discussed various possibilities of modifying the pump geometry to improve the performance of a given pump in turbine mode. The study showed that impeller rounding was the most beneficial modification. Derakhshan et al. [4] redesigned shapes of the blades using a gradient based optimization method involving incomplete sensitivities for radial turbo machinery developed by Derakhshan et al. [5] and the optimized impeller was further modified by rounding of leading edges and hub/shroud inlet edges in turbine mode.

II. METHODOLOGY

The numerical simulation CFD and the experimental setup were analyzed for performance testing. Numerical simulations and experimental test of the standard and modified impeller were carried out to compare the performance.

2.1. Modification on the Geometry

The main difference in the pump and turbine design is that, conventional turbines having flow control mechanism to increase its part load efficiency but the standard pumps are not having any flow control mechanism to increase its part load efficiency. Pumps are generally operated with constant speed, head and flow. A pump is therefore designed for one particular of operation for maximum efficiency and it not required any regulating flow control device. Turbine operates under variable head and flow condition.

In various seasonal variations of the available water so to adjust the power output and consumer requirement regulate the flow regulator are required. Also in the reverse operation of pump it may be less efficient because the direction of flow is reverse and hydraulic and frictional losses increase sharply. When fluid enters in to impeller because of round edges of impeller at the end flow separation occurs at inlet of PAT due to that separation losses occurs. In order to improve the PAT performance by reducing the losses at various sections, geometry modification in the PAT has become an interesting area of the research.

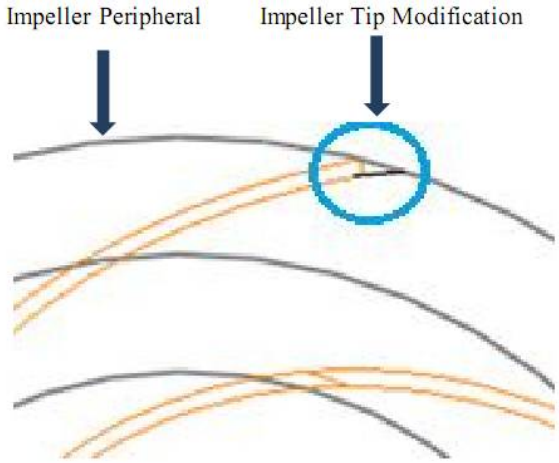


Fig.1. Rounding of Blades Profile at Impeller Inlet in Turbine Mode

Modification is performed by grinding the inlet ends of the impeller tips of the PAT round shape to preclude excessive turbulence for efficiency consideration as in Fig. 1. Then, testing is carried out by operating the pump as turbine at the maximum head and at various capacities. Method of solving problem is performed by experiment. Round tip Impeller that used in experimental test is shown in Fig.2.



Fig.2. PAT Impeller Round Tip Modification

2.2. Efficiency of PAT

The output power from the generator can be calculated by the equation,

$$P=VI \quad (1)$$

Where, P = generator output power (watt)
V = voltage (V)
I = current (A)

The efficiency is the ratio of output power from the generator to input power of the pump as turbine . The overall efficiency can get from the equation,

$$\eta_o = \frac{P}{\gamma QH} \quad (2)$$

Where, γ = specific weight of water (9806 kg/m^3)
H = pressure head at the inlet of PAT (m)
Q = flow rate (m^3/s)

$$\eta_o = \eta_m \eta_t \eta_g \quad (3)$$

Where, η_o = overall efficiency
η_m = mechanical efficiency
η_t = turbine efficiency
η_g = generator efficiency

III. NUMERICAL ANALYSIS

The Computational Fluid Dynamics (or CFD) programs are gaining in importance for the design and analysis of fluid turbomachinery. The CFD analysis of the PAT was carried out inside the premises of ANSYS Workbench 17.0. In this study, all the simulations have been performed in turbine mode and the setups were done for the same condition. The details of the numerical models for each of the domains are described below.

3.1 Modelling of the Geometry

Modeling of the geometry of a centrifugal pump running in turbine mode involves defining the impeller and volute components. Geometric modeling of draft tube is also considered since it is one of the major components in PAT system. The volute, impeller and draft tube are generated using Solidworks software.

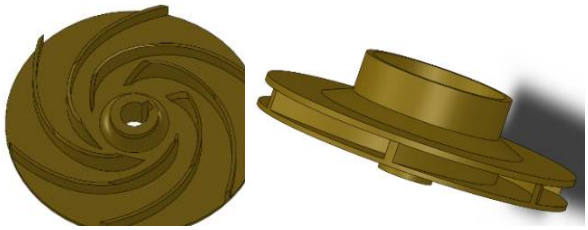


Fig.3 (a). 3D of Centrifugal Pump Impeller Model with Flat Tip

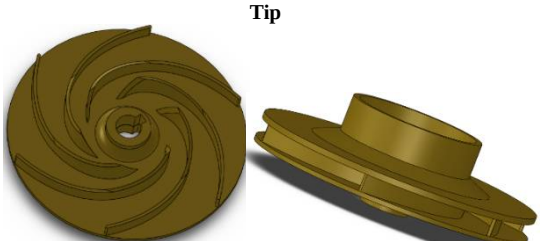


Fig.3 (b). 3D of Centrifugal Pump Impeller Model with Round Tip Modification

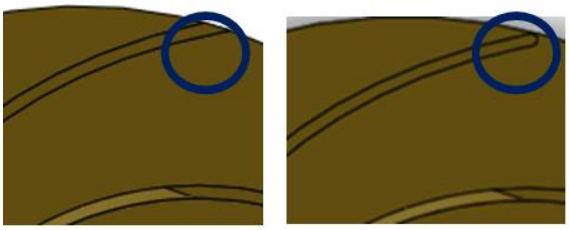
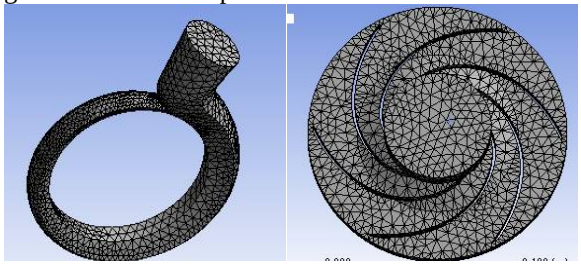


Fig.3 (c) Impeller with Flat Tip and Round Tip

3.2 . Mesh Generation

The entire geometry consisting of casing, impeller, and draft tube is modelled for numerical analysis using an unstructured tetrahedral mesh as shown in Fig.4. The geometry and the mesh of a six bladed pump impeller domain is generated using ANSYS Workbench 17.0. An unstructured mesh with tetrahedral cells is also used for the zones of impeller and volute .A total of 3570268 elements are generated for the impeller domain.



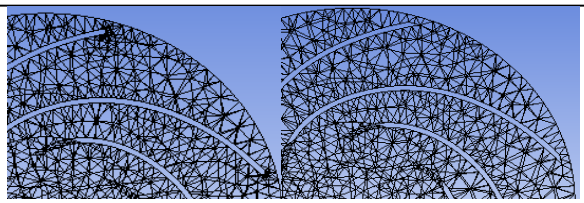


Fig.4 (a). Meshed Volute and Impeller Fluid Domain

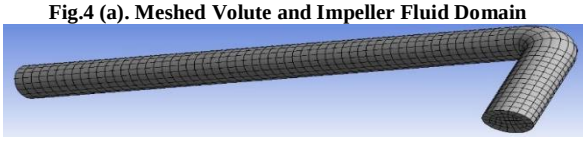


Fig.4 (b). Meshed Draft Tube Fluid Domain

3.3. Boundary Conditions

Centrifugal pump impeller domain is considered as rotating frame of reference with a rotational speed of 1655 rpm. The working fluid through the pump is water at 25˚ C. k-ε turbulence model with turbulence intensity of 5% is considered. The inlet and outlet boundary condition were set by imposing total pressure on the casing inlet surface and variable mass flow rate on the impeller outlet surface respectively.

3.4. Simulation Results

The velocity streamlines and pressure distributions with the above setup is shown in Fig.5. From the runner, the water flows towards the draft tube with high velocity.

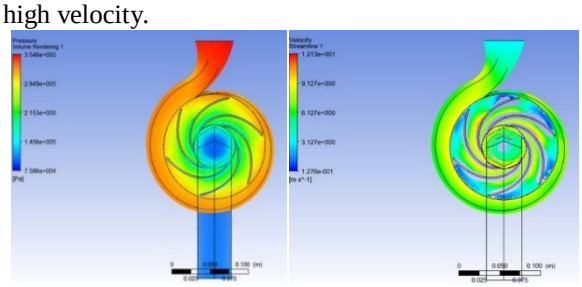


Fig.5(a) . Pressure and Velocity Distribution for the Selected Model of Original Impeller with Flat Tip

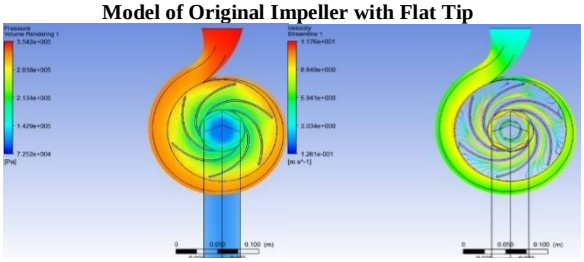


Fig.5 (b). Pressure and Velocity Distribution for the Selected Model of Round Tip Modification

By the simulation result, the pressure difference along the blade after modification is more increased than before modification.

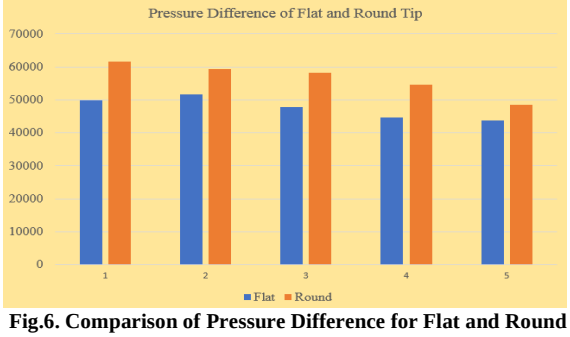


Fig.6. Comparison of Pressure Difference for Flat and Round Tip Modification

IV. EXPERIMENTAL ANALYSIS

4.1. Experimental Investigation

Fig.7 shows the general layout of the PAT experimental test rig installed in the Mechanical Engineering Laboratory at Mandalay Technological.



Fig.7. Experimental Test Rig for PAT

The test rig consists of one feed pump of radial flow type centrifugal pump for pumping. The pump has been connected with the motor. The pump operating in turbine mode was tested at the speed of 1650 rpm. Three pieces of bulbs, 100W each were used as ballast load for the generated power. A 220V synchronous AC generator was directly coupled with the pump operating in turbine mode to generate the electricity. PVC pipe with diameter of 50 mm was used for the experimental test rig and the water was re-circulated within the polythene tank having capacity of 80 gallons. A bypass pipe was connected from the main pipe to regulate excess flow and pressure.

The instruments used in the experimental rig consist of the clamp meter that used to measure the voltage and the current and the tachometer to measure the rotational speed. On/off toggle switches were used to increase the ballast load by switching on the 100W bulbs. The pressure gauge with the pressure transmitter were connected to the PAT inlet and outlet to measure the head.

4.2.Experimental results

The experiments are carried out on the PAT to find out the performance at various flow rate with impeller in modified and non-modified condition. From the measurements and calculation that have been done in the experiment as presented in Table.1and Table.2.

Table.1: Result Data of Flat Tip Impeller

Q	H_f	N_f	P_f	η_f
35	2	836	1.85	14.5
240	6.02	1423	72.9	43.1
250	9.05	1538	117	44.4
254	11.38	1583	143	42.5
262	12.17	1605	155.9	42.1
268	12.68	1622	162.6	41.1
270	13.06	1630	167.7	40.8

276	13.25	1634	171.1	40.1
278	13.41	1635	171.5	39.6
282	13.5	1650	178.2	40.2
290	13.53	1654	177.9	38.9
330	13.56	1655	179.2	34.3

Table.2.Result Data of Round Tip Impeller

Q	H_r	N_r	P_r	η_r
35	2.2	930	3.68	21.1
240	6.3	1470	89.83	51
250	9.2	1570	136.5	52.1
254	11.6	1632	155.7	46.7
262	12.5	1640	168.8	45.4
268	12.9	1645	178.7	44.5
270	13.2	1660	183.1	44.5
276	13.3	1663	186.9	43.8
278	13.58	1665	189.9	43.5
282	13.6	1668	190.3	43.1
290	13.62	1671	190.7	41.8
330	13.68	1675	192.81	41.5

Where,

Q = flow rate, (l/min)
H_f = pressure head for flat tip impeller, (m)
H_r = pressure head for round tip impeller, (m)
N_f = rotational speed for flat tip impeller, (rpm)
N_r = rotational speed for round tip impeller, (rpm)
P_f = output power for flat tip impeller, (W)
P_r = output power for round tip impeller, (W)
η_f = turbine efficiency for flat tip impeller, (%)
η_r = turbine efficiency for round tip impeller, (%)

4.3. Performance Characteristic

Experimental data obtained from the experiment are plotted in the graphs as in Figs.8.

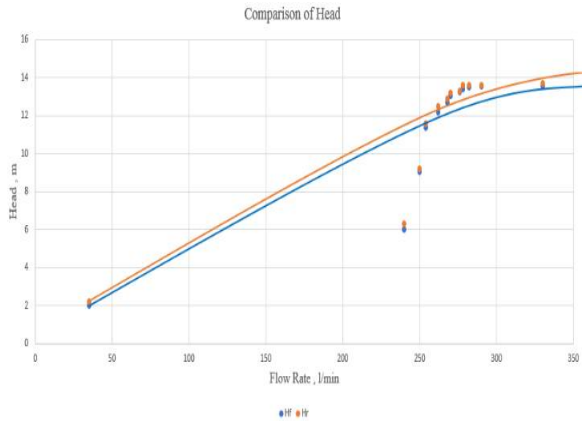


Fig.8 (a). Head Versus Flow Rate of Flat and Round Tip

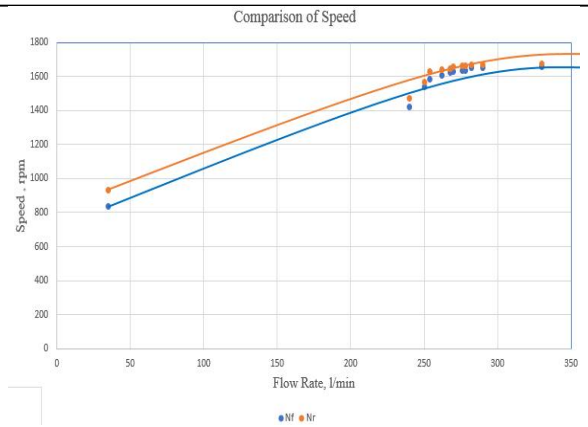


Fig.8 (b). Flow Rate Versus Speed of Flat and Round Tip

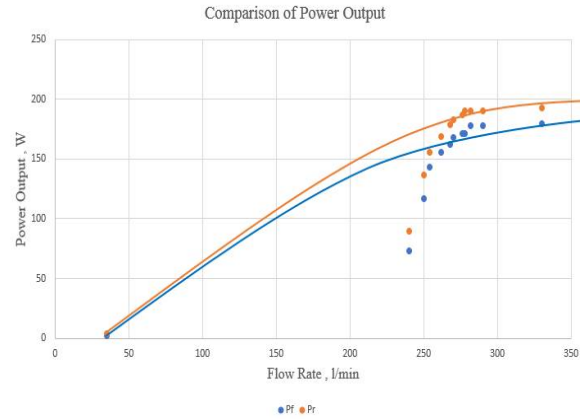


Fig.8 (c). Flow Rate Versus Output Power of Flat and Round Tip

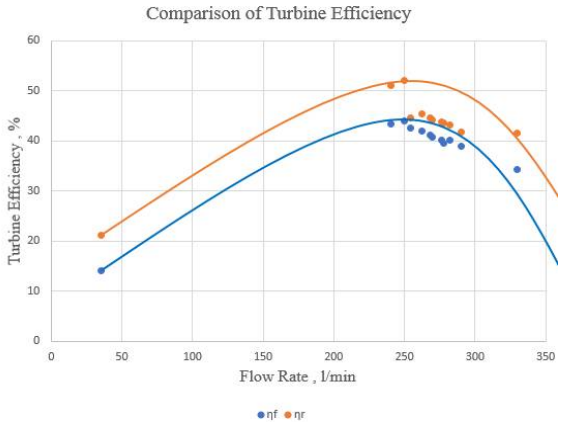


Fig.8 (d). Efficiency Versus Flow Rate of Flat and Round Tip

In these graphs, the blue color line is the characteristic line for flat tip impeller and the orange color line is the characteristic line for round tip impeller. The graph shows that the head extracted from the turbine is increasing if the flow of water capacity is increased both on before and after modification of pump impeller tips.

DISCUSSION

Efficiency of the volute-pump operating as turbine after modification its impeller tips is slightly better than before modification. Furthermore, both pumps as turbines before and after modification generate high shaft-revolution that is about 1.600 rpm at their maximum efficiency; therefore, it can be coupled

directly to the load, a generator for example, without reduction gear. The maximum efficiencies of the pump as turbine both on before and after modification are performed between the rated flow capacity of the pump at its maximum efficiency and the maximum flow capacity of the pump. In this flow range the efficiencies of the pump as turbine are relatively flatted on varying flow capacity, therefore, it could be operated at variation load. For bigger size of centrifugal volute-pumps as turbines are recommended to be modified their impeller tips for better performance. However, for the smaller pumps, they were good enough directly operated as turbines because modification is just give slightly effect on their performance but they need hard work on modification

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CONCLUSIONS

In this study, a mini-hydropower plant was installed in laboratory as test rig and centrifugal pump was tested as turbine of before and after modification of impeller tip. Experimental result confirmed the efficiency improvement in all points. Before modification, the maximum efficiency is 44% at the pressure head of 9m and the flow rate of 250 li/min. After modification, the maximum efficiency is 52% at the pressure head of 9.2m and the flow rate of 250 l/min. The impeller sharping is seen to have positive impact on the PAT efficiency with improvement of nearly 8%.

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